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ARO, Inc.

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NOTICES

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W. M. Farmer, K. S. Burgess, and J. D. Trolinger
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FOREWORD

The work reported herein was sponsored by Headquarters, Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Element 65701F, Project 4344, Task 32. The test was done by W. M. Farmer and J. D. Trolinger of Technical Staff, Office of the Managing Director, and K. S. Burgess of the Instrument Branch, Engine Test Facility, ARO, Inc., under ARO Project No. BC5016. The manuscript was submitted for publication on June 8, 1970.

This technical report has been reviewed and is approved.

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ABSTRACT

A series of experiments was performed in Engine Test Facility Propulsion Development Test Cell (J-1) at the Arnold Engineering Development Center to show that holography could be used to determine the water droplet information necessary to simulate the desired conditions in an operational environment. The experiments demonstrated the feasibility of applying holography to the visualization of small water droplet flow fields in a testing environment for droplet sizes down to approximately 15 μ.

CONTENTS

ILLUSTRATIONS

NOMENCLATURE

d	Diameter of illumination light beam
f_+	Focal length of positive lens
$f_\#$	f number of negative lens
S	Image distance
S_1	Object distance
Z_i	Reconstructed image distance
Z_o	Film to object recording distance
Z_p	Radius of curvature of the reconstruction light
Z_r	Radius of curvature of the reference light
λ_1	Wavelength of reference light
λ_2	Wavelength of reconstruction light

SECTION I
INTRODUCTION

The problem to be solved in order to simulate icing conditions on an air-breathing engine in a high water droplet flow rate, high altitude environment is to determine the water content in a supercooled droplet form before entrance into the engine over a large testing section. The limiting parameters which need to be considered are (1) the particle speed which can be as high as Mach 1, (2) particle sizes which can range from less than 1 μ up to as large as 100 μ, (3) particle densities which can be as high as hundreds of particles per cubic centimeter, and (4) the width of the flow field, which for the Engine Test Facility Propulsion Development Test Cell (J-1) is 8 ft. Furthermore, the parameters which need to be extracted from information concerning the flow are (1) the particle size distribution, (2) the particle isotropy in the flow, (3) the water content per unit volume in the flow; (4) a need to have a relatively large sample rate capacity for given flow conditions. The information required, as opposed to the limiting parameters for the technique used to sample the droplets in this kind of testing environment, places a severe restriction on the techniques which may be used with any accuracy, to sample simulated icing conditions in a high altitude environment.

Four methods appeared feasible. The first possibility is photography; however, with photography a very short depth of field is one of the limitations which must be recognized; that is, only one plane of particles at any instant of time may be observed, which means that there is only a very small sample capacity for observation of the particle field. This leads to having no acuity of the particle isotropy or the water content per unit volume. Furthermore, because of the particle speed and magnification requirements for recording very small particles, a very fast shutter and restrictive lensing magnification is required. The possible information which might be garnered from photography would be particle size and size distribution in a plane. Photography could provide a large planar sampling capacity assuming a camera with a high shutter speed and high film exposure rate is used.

The second possible solution is to use an oil slide sampling method. In this method a slide containing an inert oil is physically pushed into the flow and allowed to capture droplets which impinge on the oil. Upon removal from the flow, the slide containing these droplets is photographed through a microscope. As might be suspected, this method is inaccurate because of the unknown collection efficiency of the slide and the water droplets expanding, clustering, or evaporating upon striking the oil.

Hopefully, some knowledge of the particle size distribution might be obtained by very accurate time calibration of the exposure of the oil slide to the flow and by assuming that the droplet expansion and subsequent evaporation upon striking the oil is minimal. However, it is felt that both of these assumptions are not justified.

A third approach to recording the desired information about the droplet flow is through the use of holography. Holography has a number of requirements which are of an engineering nature before it can be applied to actual operational testing instruments. Some of the more important of these requirements include the recording of a hologram within an exposure time such that the vibrations of the system or motion of the object do not limit the hologram information (Ref. 1). This means that the hologram or the droplet cannot move more than about 1/10 particle diameter during the exposure. The images of the droplets which the hologram will reproduce are susceptible to degradation attributable to systematic noise such as dust and scratches on the lenses and film elements. The hologram can only record a certain density of droplets (assuming that the droplets are opaque) after which the recording element, usually photographic film, becomes so saturated with information that it can no longer accurately record droplet field information (Ref. 2). Holography is limited because, for very small droplets, the film must be quite close to the droplets to record and reconstruct the droplet image. However, assuming that all of the above requirements can be satisfied, a hologram can accurately reproduce the particle field and its three-dimensional characteristics from which an accurate particle size distribution can be determined. Since the field reproduced is three-dimensional, the particle isotropy in the flow can be determined, as well as the water content per unit volume (Refs. 2 through 5). Furthermore, a relatively large sample rate capacity as compared with other techniques is possible using holography.

Finally, light scattering techniques exist by which, in principle, mean size and density can be acquired through observation of the angular intensity distribution of scattered light. These methods rely heavily upon quantities which must be drawn from a theoretical model of the scattering process. It is planned to consider a detailed evaluation of scattering methods in another effort.

It was decided that, at present, holography offers the most advanced means and can produce the highest information content with the least error for measuring the droplets in the flow.

SECTION II
HOLOCAMERA DESIGN CONSIDERATIONS

2.1 CONJUGATE IMAGE OVERLAP PROBLEM

Based on previous experience and research (Refs. 2 through 5), an in-line image holocamera was chosen for the experiments. One unusual problem which can exist with such a system is known as conjugate image overlap.

The conjugate image overlap problem results from the hologram producing both a real and virtual image, and use of a lens can place images on both sides of the film during the formation process. As a result, the hologram, when reconstructed, will tend to have areas of overlapping real and virtual images from conjugate sides of the film. This means that, for a given distance from the film upon reconstruction, images may exist equally well for different areas of the object field. Figure 1 indicates these areas of image overlap, assuming all particles are on one side of the lens. For example, an image with a reconstruction distance of 1.0 (abscissa in Fig. 1) can correspond to either one of the flow positions 1.0 or 3.0 (ordinate in Fig. 1) in the object field of the imaging lens. The curves shown in Fig. 1 may be calculated using Eq. (1) and Eq. (2) (the thin lens equation) and assuming parallel light in the reconstruction

$$\frac{1}{Z_i} = \frac{1}{Z_p} \pm \frac{\lambda_2}{\lambda_1 Z_r} \mp \frac{\lambda_2}{\lambda_1 Z_o} \tag{1}$$

$$S_1 = \frac{Sf}{S - f} \tag{2}$$

where Z_i is the reconstructed image distance from the film, Z_p is the radius of curvature of the reconstruction illumination, Z_r is the radius of curvature of the formation illumination, Z_o is the object to film distance, S_1 is the object distance from the lens, S is the image distance, f is the focal length of the lens, λ_1 is the wavelength of the reference light, and λ_2 is the wavelength of the reconstruction light. While there are areas of overlapping images, techniques may be used to separate the images from the different flow positions. One method which may be used to eliminate the overlapping images is found immediately from Eqs. (1) and (2). It is seen that by making Z_r negative (placing the film immediately next to the lens) no overlap will exist for any S_1. This would mean, however, that magnification would be limited to a value less than or equal to one. A second technique which may be used is found by observing that placing the entire object field between 2 and 0 focal lengths

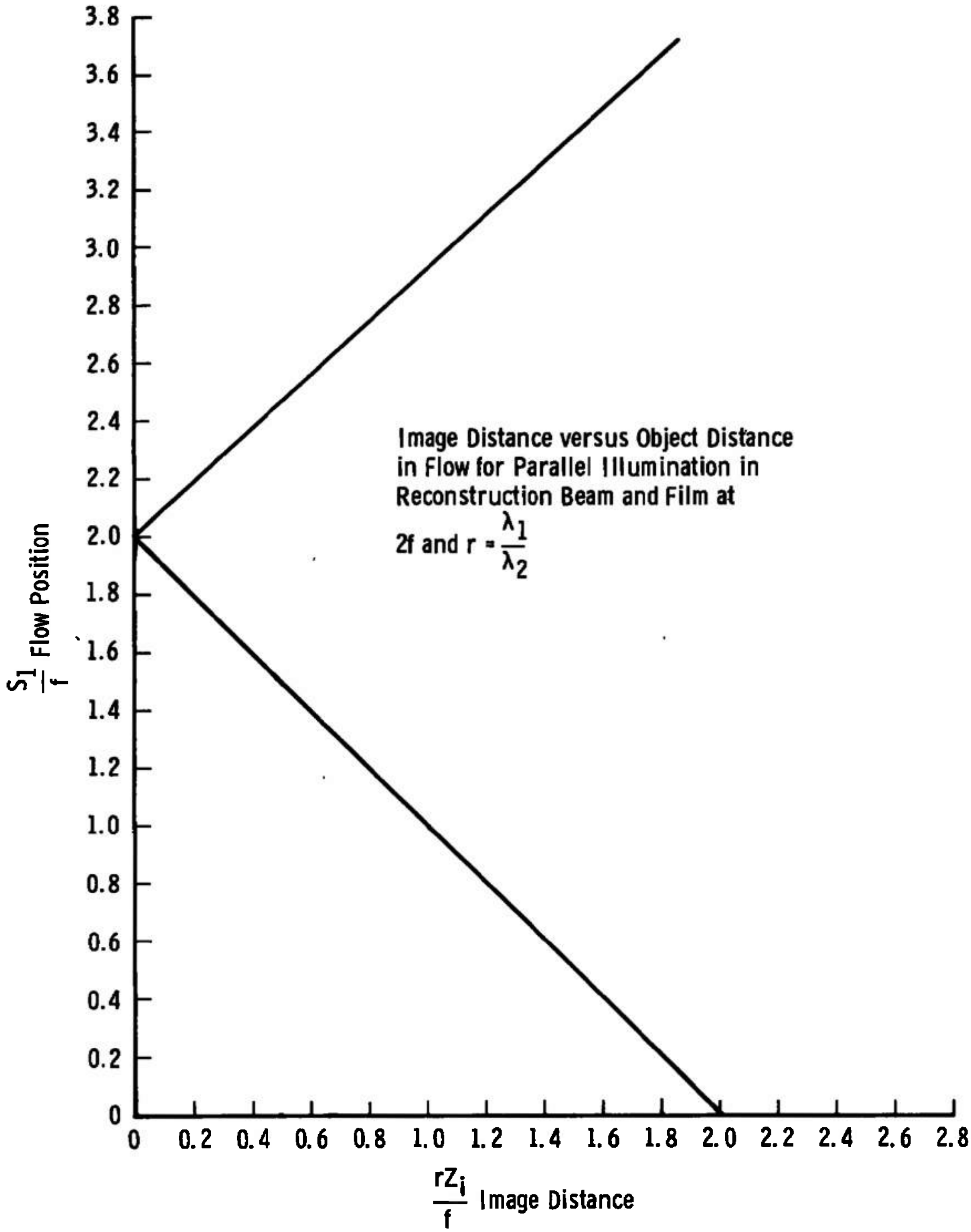


Fig. 1 Curves Depicting Flow Position as a Function of Image Distance for Parallel Reconstruction Illumination

away from the lens, causes the entire object field to be imaged on only one side of the film.

The problem of overlapping images can cause serious errors in the data obtained from the reconstruction of the hologram since, for data analysis in an area of overlapping images, there would be no way to distinguish particles which have different magnifications. This means that the measurements would be in error by the scale factors induced in the measurements by the magnification of the particle fields. To eliminate this source of error, parallel light reconstruction must be used in order to make the magnification constant throughout the field (Ref. 5).

2.2 FILM REQUIREMENTS

One of the principal considerations in the design of the holocamera for a specific application is film. Since nearly all holograms and all operational holocameras make recordings on film, film requirements deserve the utmost consideration in specific holocamera design. The principal considerations used for choosing film are (1) the physical film size, (2) the resolution required (the spatial frequency cutoff), (3) the linearity of the film, (4) the noise characteristics of the film, and (5) the exposure or optical density requirements for the film (Refs. 1, 2, and 6).

The determination of film size follows from considerations of imaging optics and film frequency cutoff (the resolution) and the size of the objects which are to be recorded. If a lens is used, the film resolution should be sufficient to record at least all the spatial frequencies which the lens can pass; and, for a high quality lens, this is on the order of 300 to 600 lines/mm. Film resolution needs to be even higher if a lens is not used. Furthermore, operation in the nonlinear portion of the film reduces the power which can be projected into the hologram image. The noise characteristics of the film are tied primarily to developing techniques, to the linearity of the film, and also to the film grain size. Proper developing and liquid gate techniques, which will be discussed, usually eliminate most of the noise characteristics associated with the film. Finally, the optical density of the exposed film for a good hologram usually needs to be high for small particles in order to record the weak intensity, high spatial frequencies which help to clearly define the image of the object. The optical density is related to the linearity and dynamic range of the film and thereby sets definite limits on what can and cannot be recorded for a given type of film.

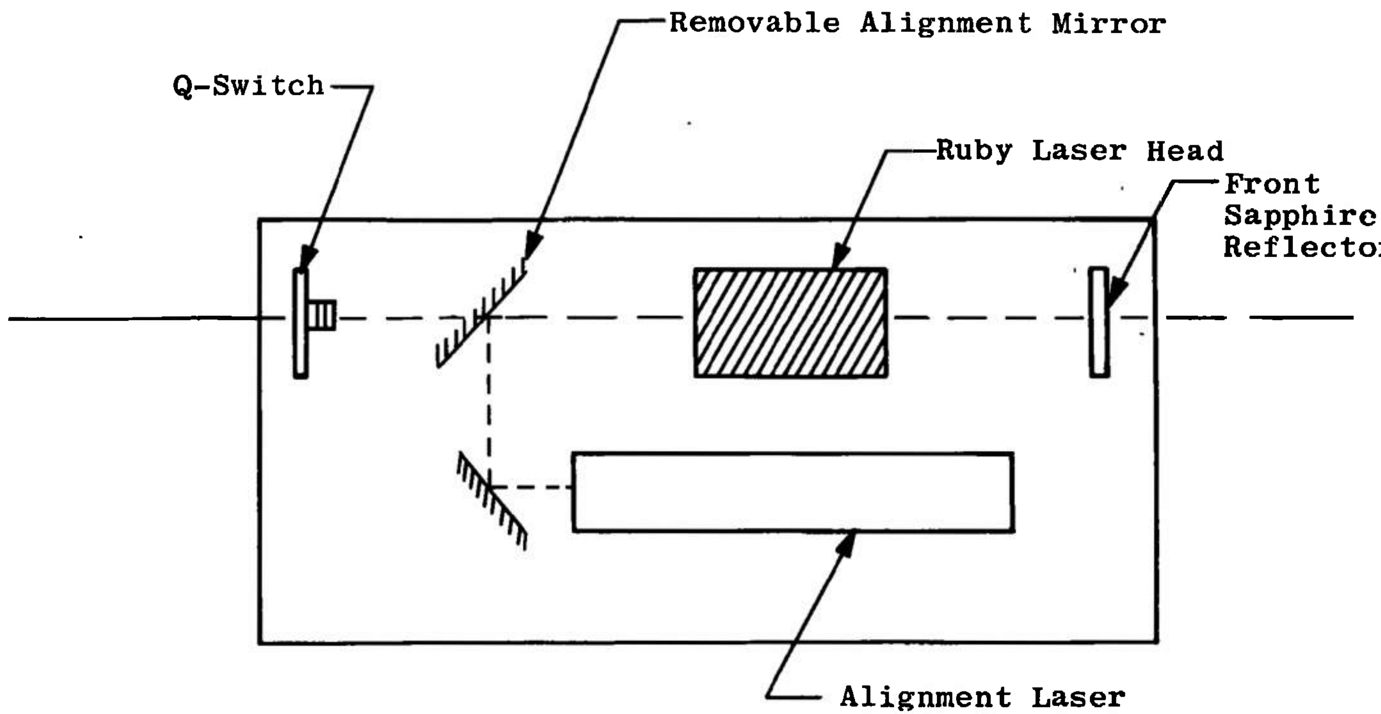
SECTION III
EXPERIMENTS IN THE TEST CELL

3.1 APPARATUS

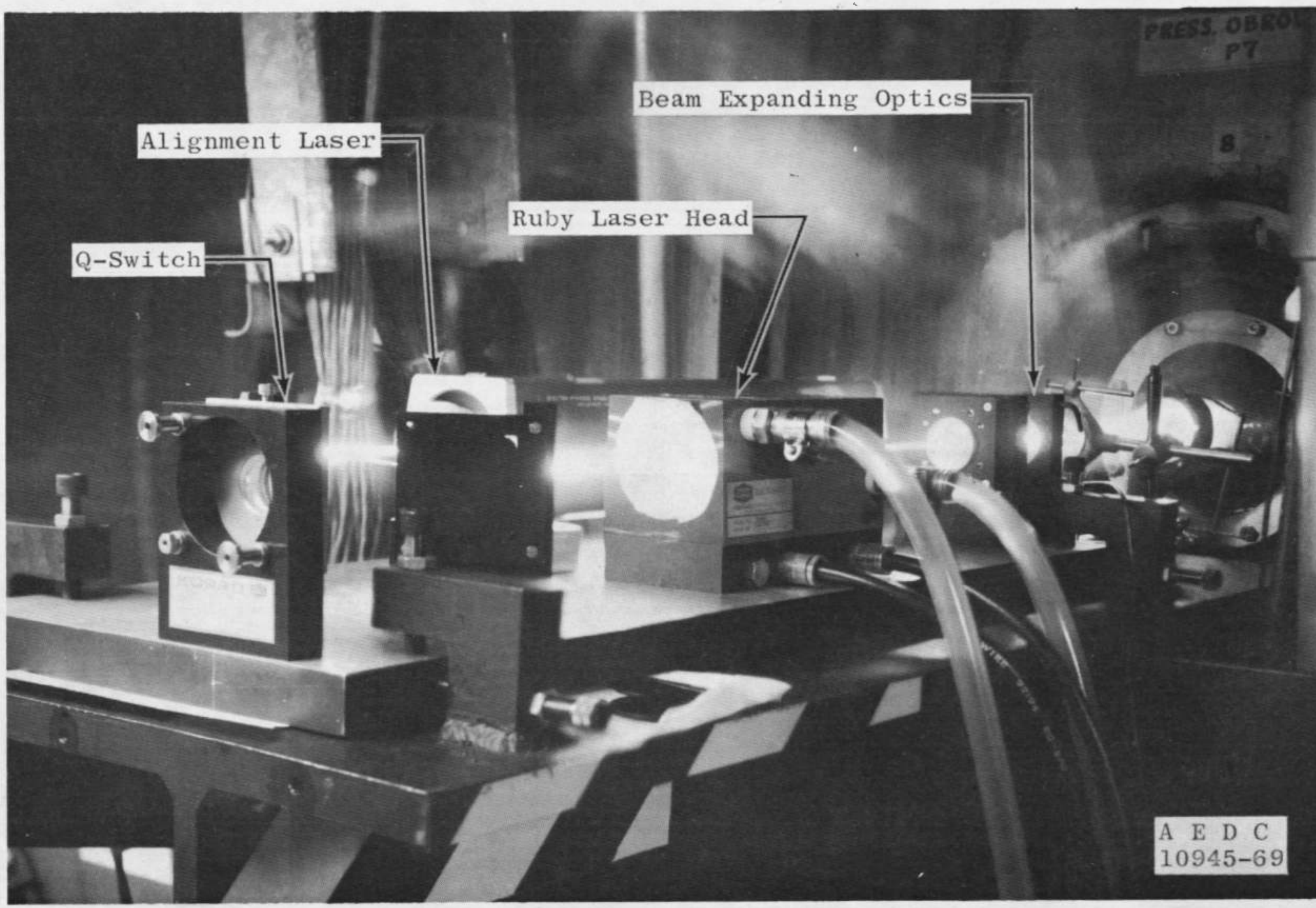
The laser used in these experiments was a Korad® K1 pulsed ruby laser. Used in a Q-switch mode, this laser can produce up to 1.0 joule of energy. Since there was little beam attenuation across the flow section of the test cell, this energy was considered more than adequate for properly exposed holograms. For the experiments discussed in this report, the laser was Q-switched using a flat-flat liquid dye cell. The dye employed was cryptocyanine in a methanol alcohol base. To guarantee that the laser pulsed in a single transverse mode, a small cavity aperture 2 mm in diameter was used. In addition to the pulsed ruby laser, a low power CW helium-neon laser was used for aligning the pulsed laser, the beam expanding optics, and the holocamera box. This laser was mounted so that the alignment could be made through the ruby laser cavity. In this manner precise knowledge was available as to exactly where the light from the pulsed laser would go in hologram formation. Furthermore, the alignment laser was used during the actual test runs to ascertain that the optical elements were not displaced because of the high vibration levels. Figures 2a and b illustrate the laser arrangement. A photodetector was used to detect the laser pulse. The photodetector response was recorded on an oscilloscope to guarantee that only a single laser pulse was allowed by the Q switch. The laser pulse duration of 10 to 20 nsec guaranteed that there was essentially no droplet motion during the hologram exposure. Thus, the Q-switch produced an effective shutter so that motion during the holographic recording of the particle fields was negligible.

There are essentially two sets of lensing elements which must be considered in the design of the holocamera. These lensing elements are the expanding optics for the laser beam as it leaves the laser and the imaging optics which are located in the holocamera box. There are two standard types of expanding optics. The first type, and the one which was used in these experiments, is a small negative-large positive lens combination. The positive lens is positioned with respect to the negative lens such that their focal points coincide. This means that light emerging from the positive lens is parallel and expanded. The final diameter of the expanded beam is given by

$$d = \frac{f_+}{f_-} \qquad (3)$$



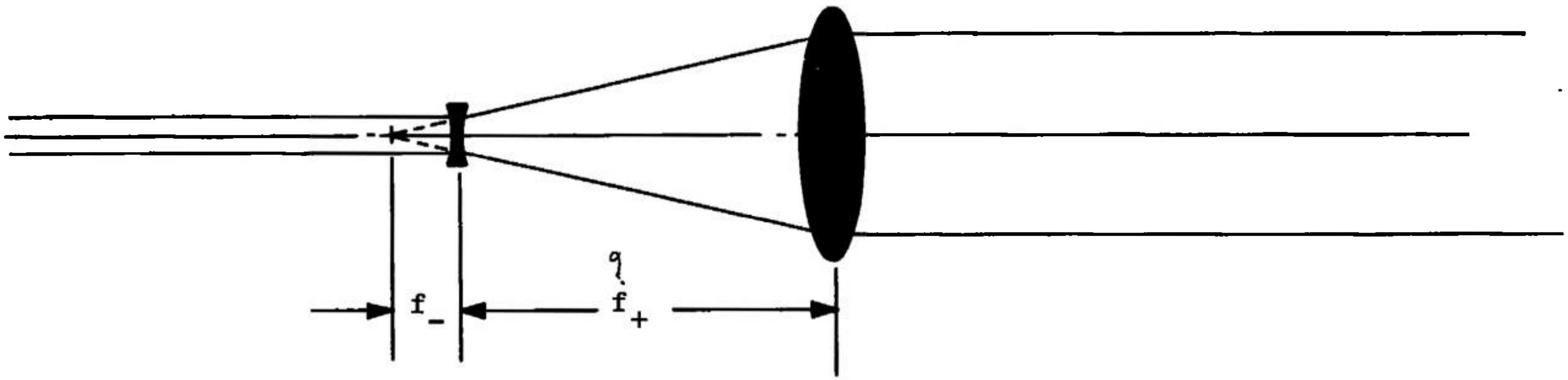
a. Schematic
Fig. 2 Laser Arrangement



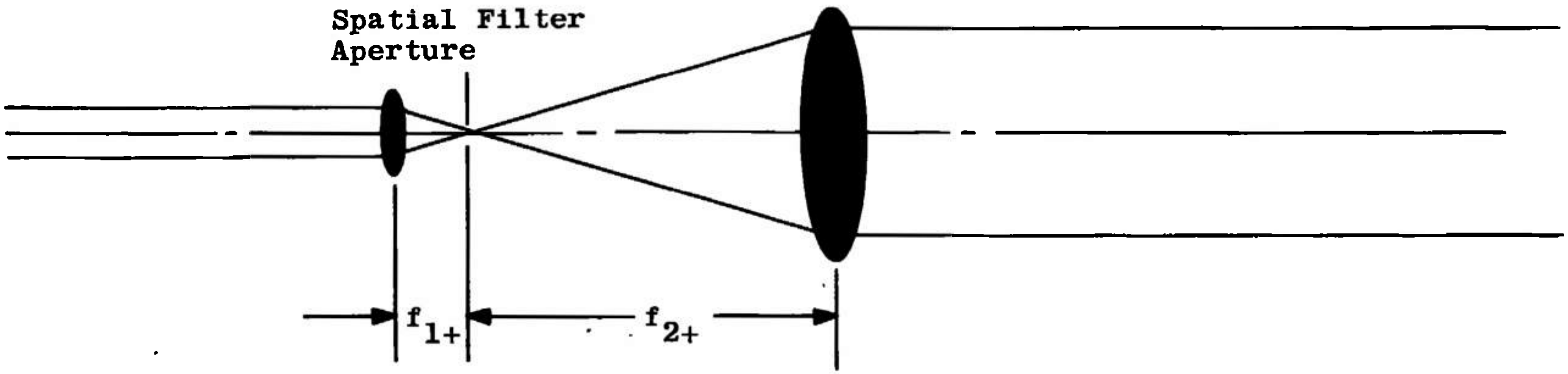
b. Photograph
Fig. 2 Concluded

where f_+ is the focal length of the positive lens, and $f_\#$ is the f/number of the negative lens. The small negative lens sits immediately adjacent to the laser and provides the initial beam expansion. This type of beam expanding optics (Fig. 3a) is the easiest to work with in a high vibration environment and, furthermore, eliminates the danger of any lens damage from the highly intense light as it initially leaves the laser. A second and more preferred type of beam expanding optics is that shown in Fig. 3b. This type of optics can produce a much cleaner expanded beam. The term clean in this sense implies the beam is free of systematic noise in the light such as interference patterns from dust particles on the lensing elements. The first lens is a small positive lens with a relatively high f/number which focuses the light through a small pinhole before it expands and strikes the large positive lens which collimates the light into a parallel beam. Again, the positive lens is placed with its focal point coincident with that of the first lens. The principal problems associated with this second type of expanding optics are that a high f/number small positive lens must be used initially in order to prevent the power from the ruby laser from destroying the small pinhole (on the order of 30 to 50 μ) and the fact that this arrangement is highly sensitive to vibration in that only a small vibration is required to shift the light from the small positive lens off the pinhole, thereby blocking the beam passage to the holocamera box. The principal consideration when selecting beam expanding optics is the desired size of the beam and the cleanliness required in the beam. For these experiments a negative-positive lens combination provided a 2-in.-diam beam.

For the imaging optics, it was determined that a telescope lens with a focal length of 48 in. and a diameter of 6 in. was sufficient with the 2-in. illumination. In order to check the resolution of the primary imaging lens, the lens was set up in the laboratory in conjunction with the beam expanding optics and a wire grid having different wire sizes positioned at various points in the object space of the lens. Holograms were taken of these wire grids, and the reconstructed images were evaluated. The wire grids, and the reconstructed images were evaluated. The wire grid was also observed without any holographic recording in order to determine the optimum lens performance. It was found that the hologram could record wire sizes of approximately 25 μ and, by observation of the 25-μ wire image, it was determined that probably the smallest object that could be recorded using this lens was 15 to 20 μ with unit magnification. With a magnification of 4, a wire 6 μ in diameter could be observed. However, this wire was not seen in the holographic recording. Since it was desirable to observe particles smaller than 15 μ (down to 2 or 3 μ), a short focal length 2-cm f/4 camera lens was used in order to obtain increased magnification. This was done primarily as a check to see if less than 15-μ particles could indeed be recorded. The position of the



a. Negative-Positive Lens Combination



b. Positive-Spatial Filter-Position Lens Combination

Fig. 3 Negative-Positive and Positive-Spatial Filter-Positive Lens Combinations for Beam Expansion

short focal length lens is shown in Fig. 4. As may be observed, the hologram images which were reconstructed using this arrangement have definite errors in that there was a conjugate image overlap problem using this type of lensing arrangement. For particles very close to the focal point of the second lens, a magnification of approximately 20 times can be obtained, and small particles on the order of 5 μ can be observed. It will be necessary for high magnification to use a modified lensing combination in order to eliminate the conjugate image overlap problem. It is believed that this can be done by using a series of large negative and positive lenses in tandem. It should be noted that with the small lens in place, the effective depth of field was greatly reduced for the magnifications with which it was possible to see 5-μ particles. The depth of field was on the order of 1 to 2 in. It should be noted that because of the high probability of noise in these data, the measured sizes cannot be taken as definitive and further research in this area is required. Figure 5 is a photograph of the actual holocamera box. The primary imaging lens was contained in the box along with the film holder and mirrors in order to properly fold the beam of light which contained the hologram information into a sufficient space convenient to work with. The mounts for the lenses and mirrors had several requirements. The lens mount had to be such that the lens could be mounted rigidly and would not be susceptible to shaking loose during the vibrations which were experienced during the actual testing time. Furthermore, it was necessary that the mirrors have rotational adjustments about two orthogonal coordinates lying in the plane of the mirror. The mounts for the mirrors and the lens were in turn mounted on standard optical bench mounts which were positioned on standard optical rails to thereby be positioned at relatively any point in the box, as can be seen from Fig. 5. The mirrors were large enough to enable all the radiation collected by the aperture of the primary imaging lens to reach the film. These mirrors were high quality, first surface, quarter-wave flat mirrors with an aluminum coating. With a metallic coating such as aluminum, a 10- to 20-percent loss of power for each reflection is experienced. However, with the power which is available from the ruby laser, this was not deemed a limiting factor in their use. When power requirements from the laser do become critical, it would be quite easy to obtain perfect reflections using high quality dielectric mirrors.

The film used was a high quality, 70-mm film produced by the Afga-Gaveart Corporation. The film was mounted in a film pack which had an automatic film advance which could be controlled from the laser side of the test cell by the laser operator. Although this film pack was sufficient for the experiments described here, it is deemed desirable that several modifications be made to the film pack in order to expedite

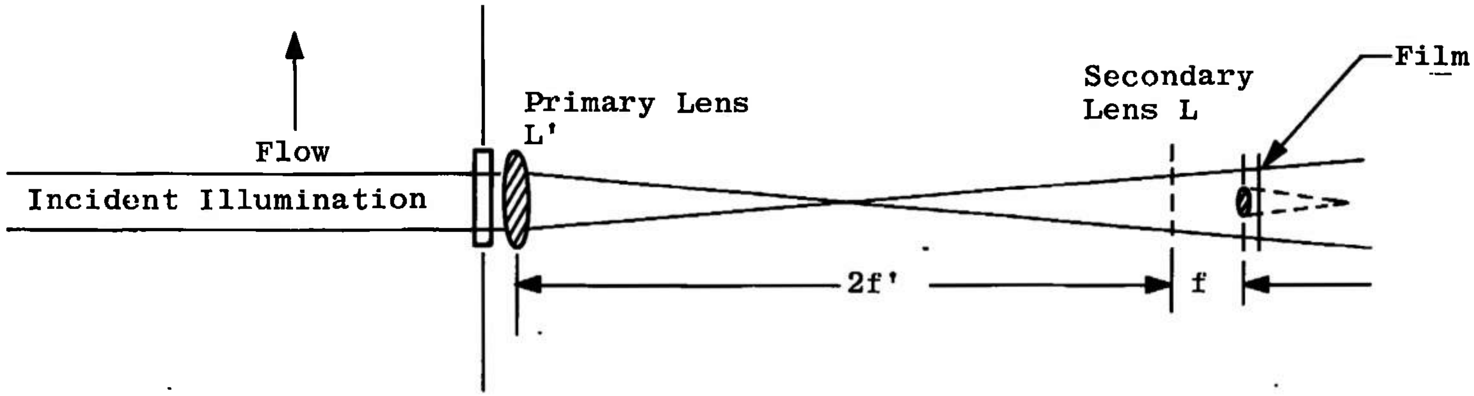


Fig. 4 Position of Small Magnifying Lens

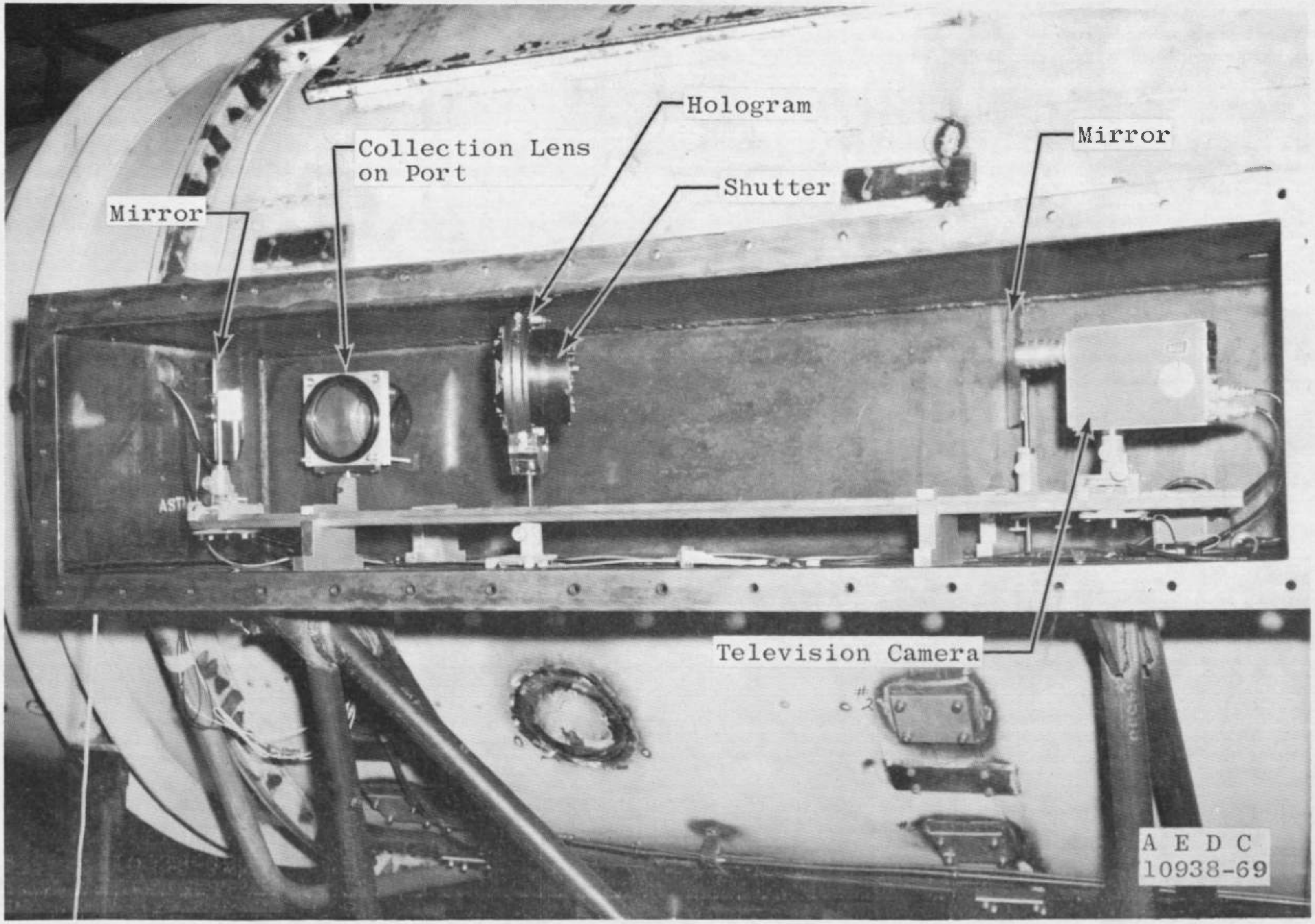


Fig. 5 Photograph of Holocamera Box

film processing which is an important, if not the critical, factor in the recording of the hologram. The major modification would involve changing the film pack such that the exposed film could be removed from the pack one frame at a time and developed accordingly. The reason for this modification lies in the fact that some exposures of the film will be more strongly exposed than others because of different flow conditions and, as a result, greater beam attenuation. Therefore, with less exposure, longer development times are required in order to obtain equivalent optical densities for the film. This is quite important for equivalent data from one hologram to the next.

A television camera was placed in the holocamera box and focused such that the light incidence at the film plane from the alignment laser could be observed.

A monitor to observe the image from this camera was placed on the laser side of the test cell so that the holocamera operator could take periodic optical alignment checks using the alignment laser light and ascertain that all components were in position and were not vibrated out of place. It is felt that with proper design for the optical and lens mounts that the necessity of a television camera in the film box can be obviated.

The quartz ports which were used for the experiments had to be of high optical quality since in-line holography was used in the camera (Ref. 1). It was determined that the two surfaces of each port had to be parallel to within 10 seconds of arc and had to have a surface flatness of at least one quarter of the wavelength of light which was used. Furthermore, to eliminate spurious noise, it was necessary that these ports be bubble free and of the highest optical quality. During flow operations, a high-pressure purge using air or dry nitrogen was necessary in order to keep water droplets from condensing and forming on the ports. With water condensation on the ports, a great deal of noise is introduced in the holograms, and the effective area in which the holographic recording is made is reduced to only that area where there is no water condensation. Figure 6 is a photograph of a hologram made when the port purge was insufficient. The streaks across the hologram were attributable to water droplets running across the port, and in these areas there is no information which may be garnered with respect to the flow.

All the above apparatus comprised the holocamera used to make the water droplet holograms. Figure 7 is a schematic of the holocamera system.

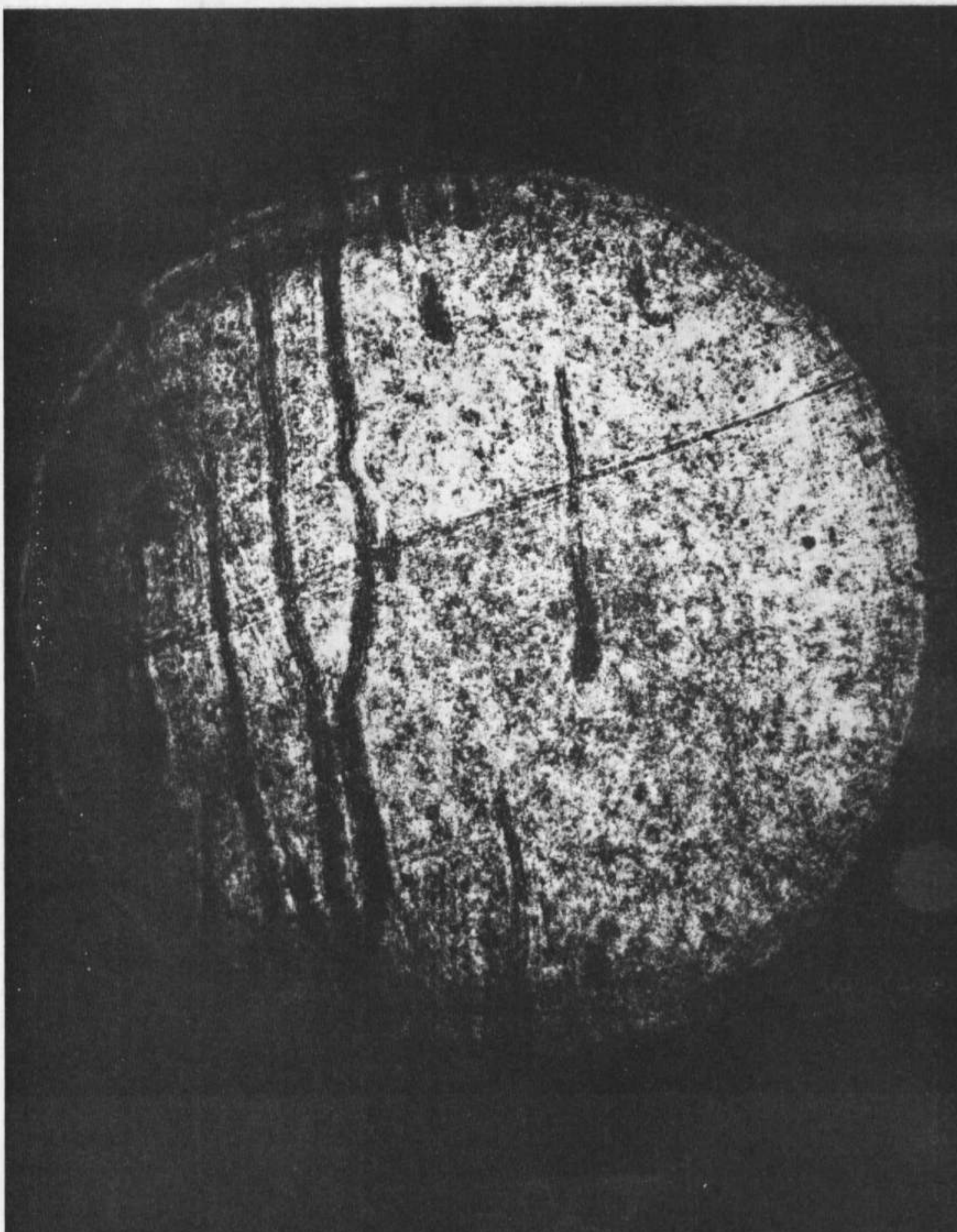


Fig. 6 Photograph of Water-Streaked Hologram

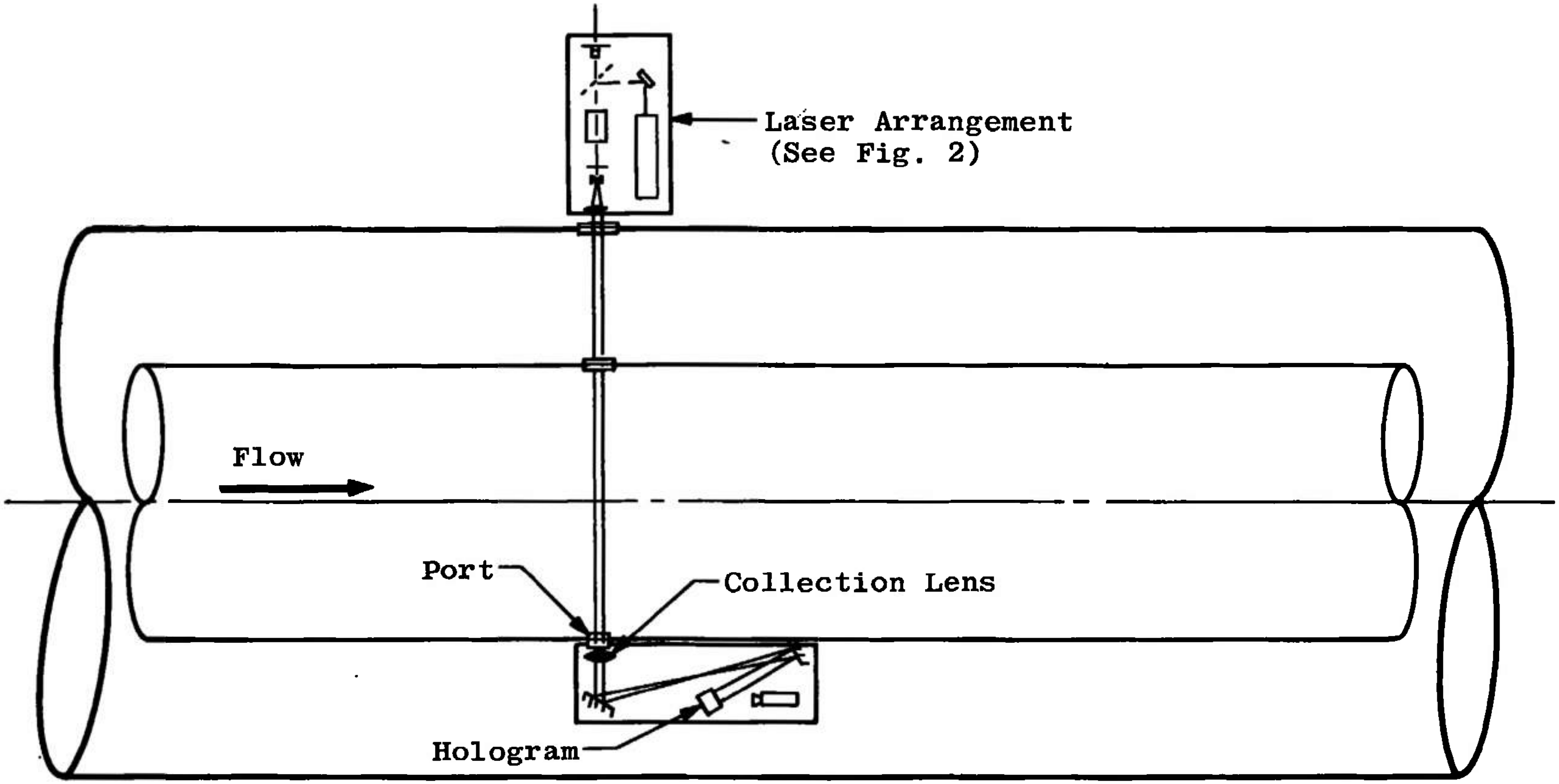


Fig. 7 Schematic of Holocamera System

3.2 DATA ACQUISITION AND REDUCTION

To make a hologram at a given flow condition, the following procedure was followed. An alignment check was initially made using the alignment laser and television monitor to determine that all the optical components were in place and not changed resulting from prior operation. Once this check was established, a standard safety procedure was followed whereby all test cell personnel were forewarned that the ruby laser would be fired and that all observation ports should be closed. Using these methods, the following holograms were taken for several different flow conditions. For flow conditions at a cell pressure of 7.04 psia and air velocity of Mach number 0.45, holograms were made of water flows for volumetric flow rates of 0.5, 1.0, and 1.5 to 2.0 g/cu m. The air velocity was then changed to Mach number 0.3, and the same sequence of holograms was repeated for different volumetric flow rates of water.

With these experiments, holograms could be taken immediately after flow conditions were changed. If necessary, it is believed that approximately one hologram per minute could be taken. However, because of the large time lapse between changes in flow conditions, this was not an essential point of interest. It may be interesting to note that in a side-by-side comparison the holographic procedure proved to be many times faster than the oil slide procedures which were performed simultaneously with the holography.

After the holographic recordings were made, the film was developed to a nominal optical density of 1.8 to 2.0. Since the photographic emulsion was mounted on a celluloid substrate, this film was quite susceptible to film grain noise and surface irregularities. In order to compensate for this, liquid gates were made to enclose the individual holograms. The liquid gate consists principally of a coating of mineral oil, of which the index of refraction very nearly matches the index of refraction of the film emulsion, which is placed on both sides of the film and is then encased between two glass slides. The glass slides were sealed around the edges, and the hologram was then ready for data analysis. The hologram is analyzed in the reconstruction apparatus shown in Fig. 8. The essential elements of this apparatus are a CW laser, an imaging lens for increased magnification of the images, an optical mount to hold the hologram, and a micropositioner to position a d-c spatial filter at the focal point of the imaging lens and some means of observing the reconstructing images, either a frosted glass, photographic film or in the case of these experiments a television camera and monitor system. The laser used in the reconstruction apparatus had 15 mw of power at 6328 Å, was operated in a TEM_{00} CW mode, and was used with a small low-pass spatial filter similar to the one previously discussed. The light was made

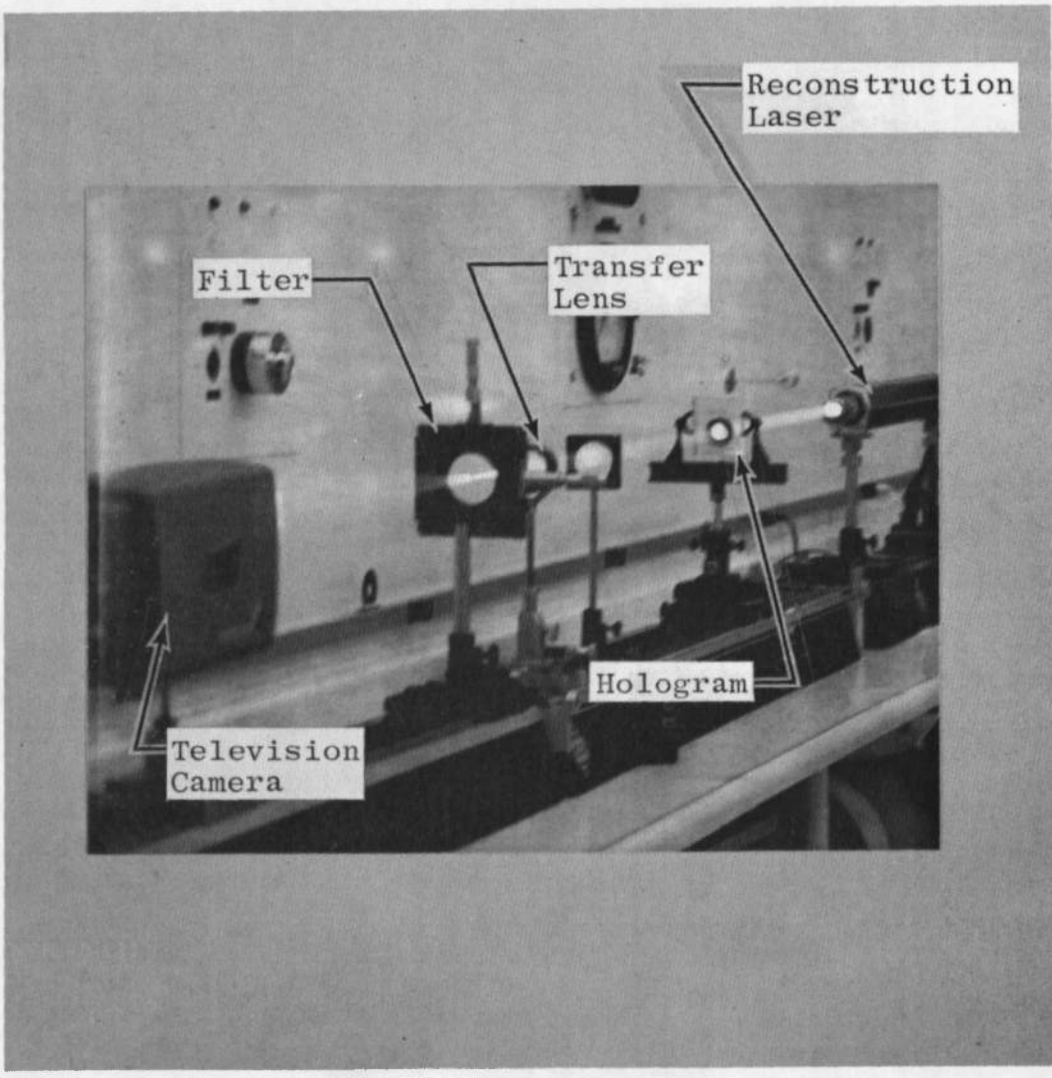
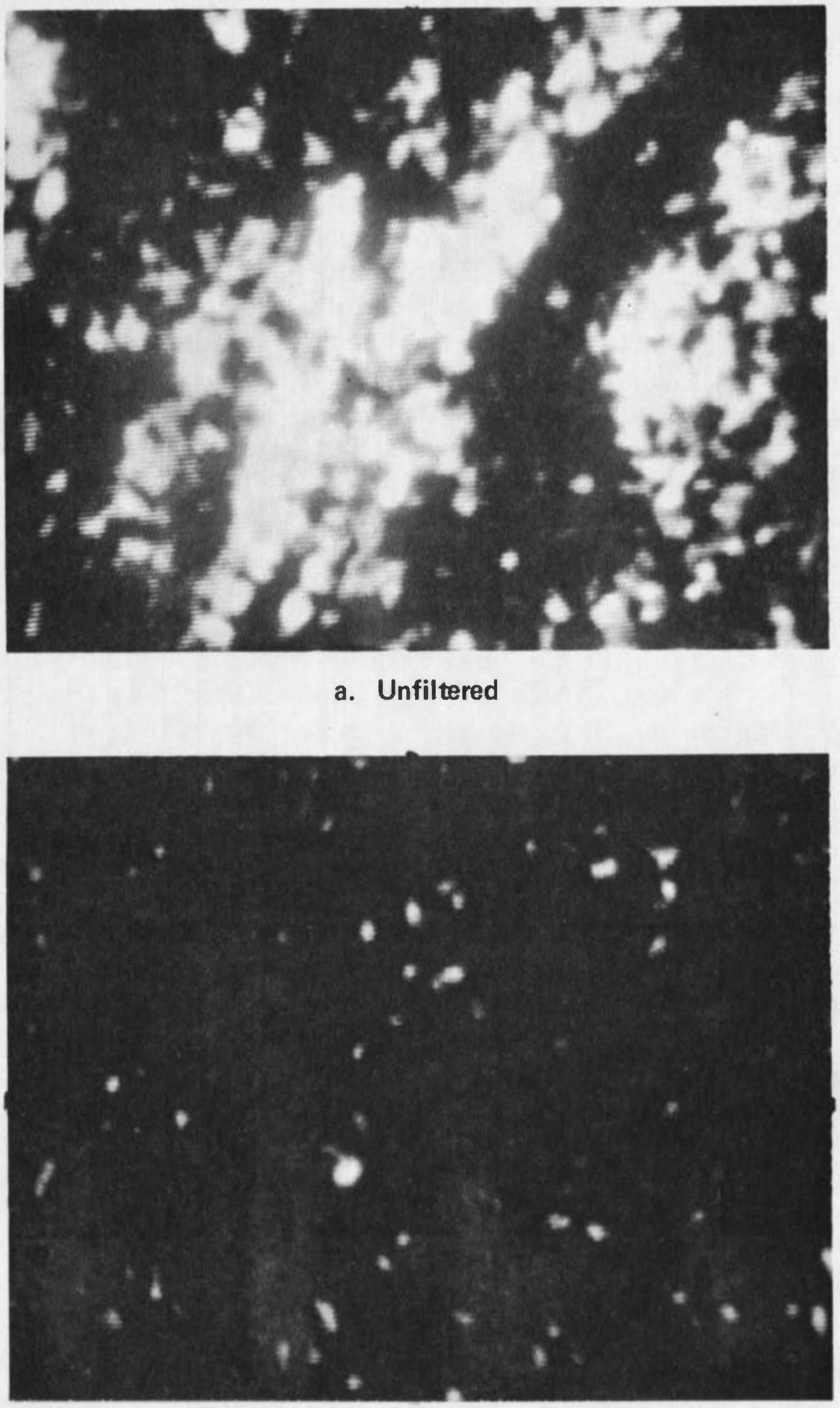


Fig. 8 Photograph of Reconstruction Apparatus

parallel from this laser before its incidence on the hologram for constant magnification in the image field. Variations in magnification may be made by using either converging or diverging spherical wave illumination during the reconstruction process. The relatively high power which is required from the reconstruction laser may be understood from the following considerations. In order to produce relatively noise-free images from the hologram during reconstruction, it is necessary to use a d-c spot or absorbing dot at the focal point of the lens. This d-c spot removes approximately 95 percent of the light which passes the reconstruction apparatus. Furthermore, the diffraction efficiency of the hologram which is defined as the light power incident on the hologram divided into the light power which goes to form the hologram images is only about 1 percent; each glass surface in this system reflects approximately 8-percent incident light, and the imaging lens expands the hologram images for seven times magnification before the incidence upon the television camera. When all of these considerations are made, it is found that there is less than 1 μw/sq cm of image which is available to the television camera. For the vidicon image which was used, this proved sufficient; however, in order to analyze the particle images which were displayed on the television monitor, it was necessary to increase the contrast which also effected a reduction in available image power, thereby placing limits on the ability to observe small or weak images. A grid work of wires ranging in size from 25 to 125 μ was placed in the object space on the imaging lens, and imaged on the television camera. In this way the position of the reconstruction particles with respect to the film plane could be accurately determined, which in turn could be used to determine the possible particle positions in the actual flow. The wire grid served a second purpose in that a wire of known size imaged on the television monitor could be used as a scaling reference with which to determine the magnification of the system. The imaging lens used was a diffraction limited, f/4 two-inch collimating lens, the same type which was used in the beam expanding optics. Once the particle field was properly imaged and systematic noise reduced, a camera was used to photograph the image of the particle fields which were on the television monitor.

3.3 EXPERIMENTAL RESULTS

Figures 9a and b are photographs taken from the television monitor of the reconstructed particle field image. Figure 9a is a photograph of an image made without using a d-c filter. Figure 9b is made with the d-c filter in operation on the same image field. By comparison it is seen that the d-c filter contributes considerably to noise reduction in these hologram images. These reconstructions are from holograms made



a. Unfiltered

b. Filtered

Fig. 9 Unfiltered and Filtered Reconstructed Droplet Images

from the particle field with a water flow rate of 0.5 to 2.0 gm/cu m and at a Mach number of 0.45. Figure 10 shows several particle size histograms which were taken from measurements of these and other photographs of different positions in the flow.

It is of interest to compare data obtained using the oil slide method with that obtained using holographic techniques. Figure 11 is a photograph taken through a microscope of water droplets which had been collected on an oil slide. Note that all of the images appear circular, whereas the hologram images show that the droplets are distorted from this shape when undisturbed by the sampling method. Figure 12 is a histogram obtained from this photograph; and, as may be observed, the histograms compare favorably although, as might be expected, the particle sizes from the oil slide histogram are a little larger than those obtained by the holographic technique.

There are several sources of error which may be associated with the data obtained from the holographic images. Probably the largest component of error is that attributable to systematic noise in both the recording and reconstruction phases using the holocamera. During the recording, the hologram will record all objects which lie in the path of the light beam. As a result, if there is dust in the air of sufficient size, the hologram will record dust which is not actually in the flow, dust particles which have collected on the lenses and mirrors in the camera box, and any striations in the optical ports. Thus, it is relatively easy to confuse systematic noise with the actual particle field data. Therefore, extreme cleanliness is required for all the optical components and the environment surrounding the holocamera box. The same problem exists during reconstruction where the images that are reconstructed are even more susceptible to systematic noise than during formation. Again, utmost cleanliness is required for the lens and other glass elements which are in the system. Furthermore, the reconstruction apparatus should be vibration free to ensure that the images do not change positions while the measurements are being made. The photographs shown in Figs. 9a and b were made with a relatively fast exposure time as compared to the vibration of the reconstruction system. However, if an observer watched the reconstructed images on the television monitor, they would appear to twinkle because the optical bench on which they were being reconstructed was vibrated by the air conditioning which was present in the room.

A second source of error is in the particle edge definition. Furthermore, the focal depth of the particle images can be many particle diameters, thereby making the exact position of the particle image questionable. The maximum plane of focus (which corresponds to the correct Z_o position) for the image can be determined by bringing the image in and out of focus and seeking maximum center intensities.

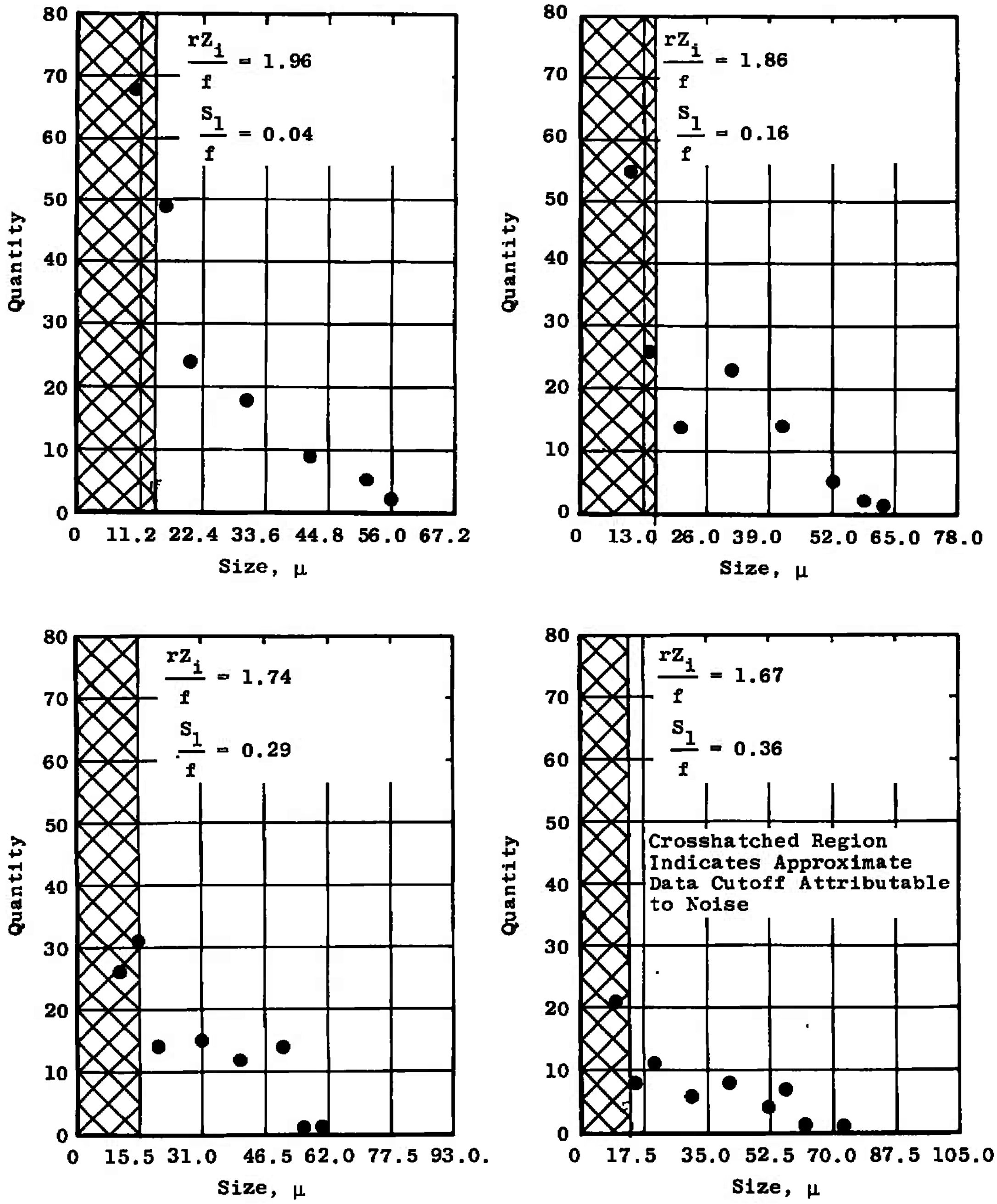


Fig. 10 Particle Size Histograms Made from Reconstructed Hologram Images

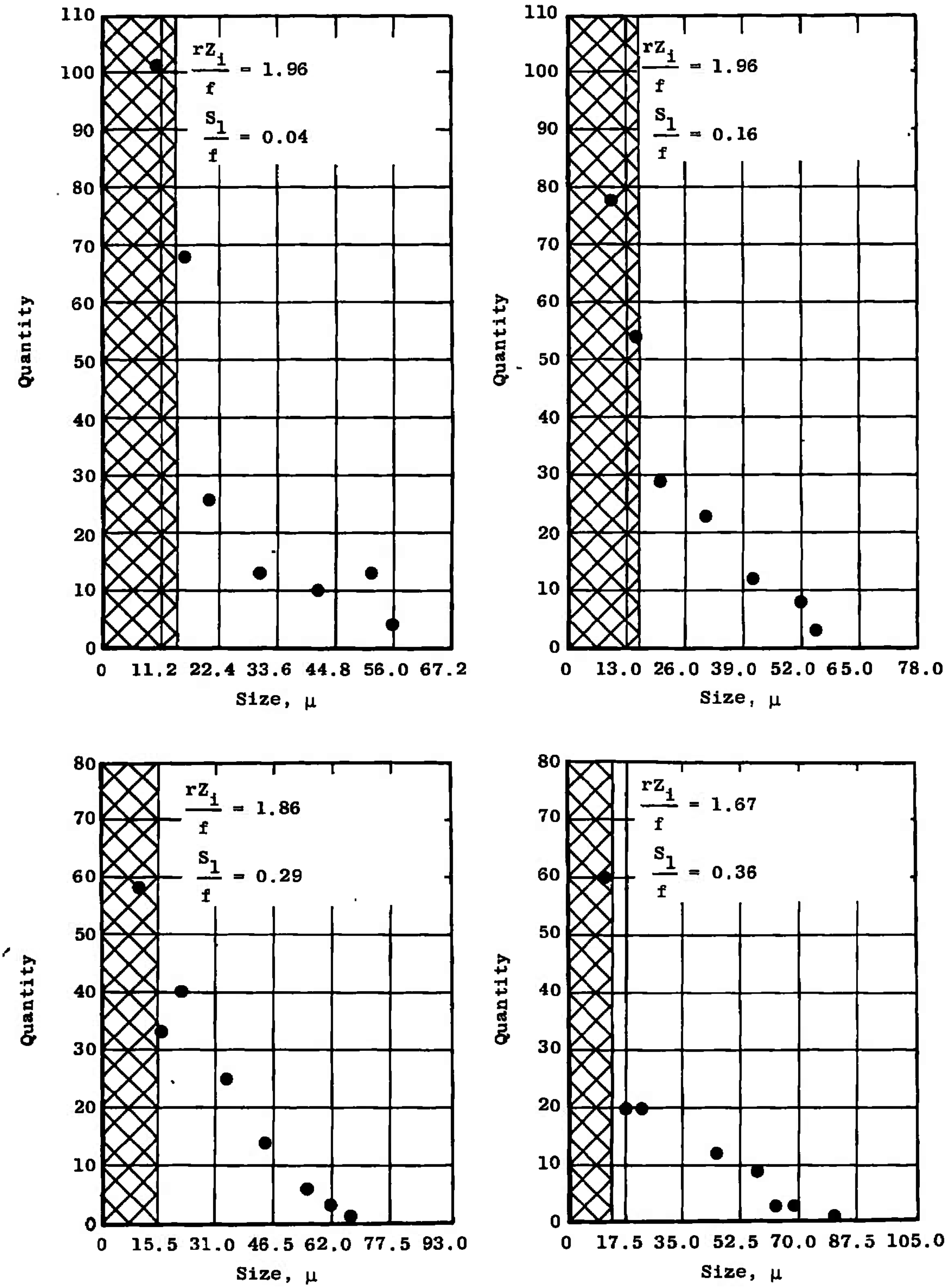


Fig. 10 Concluded

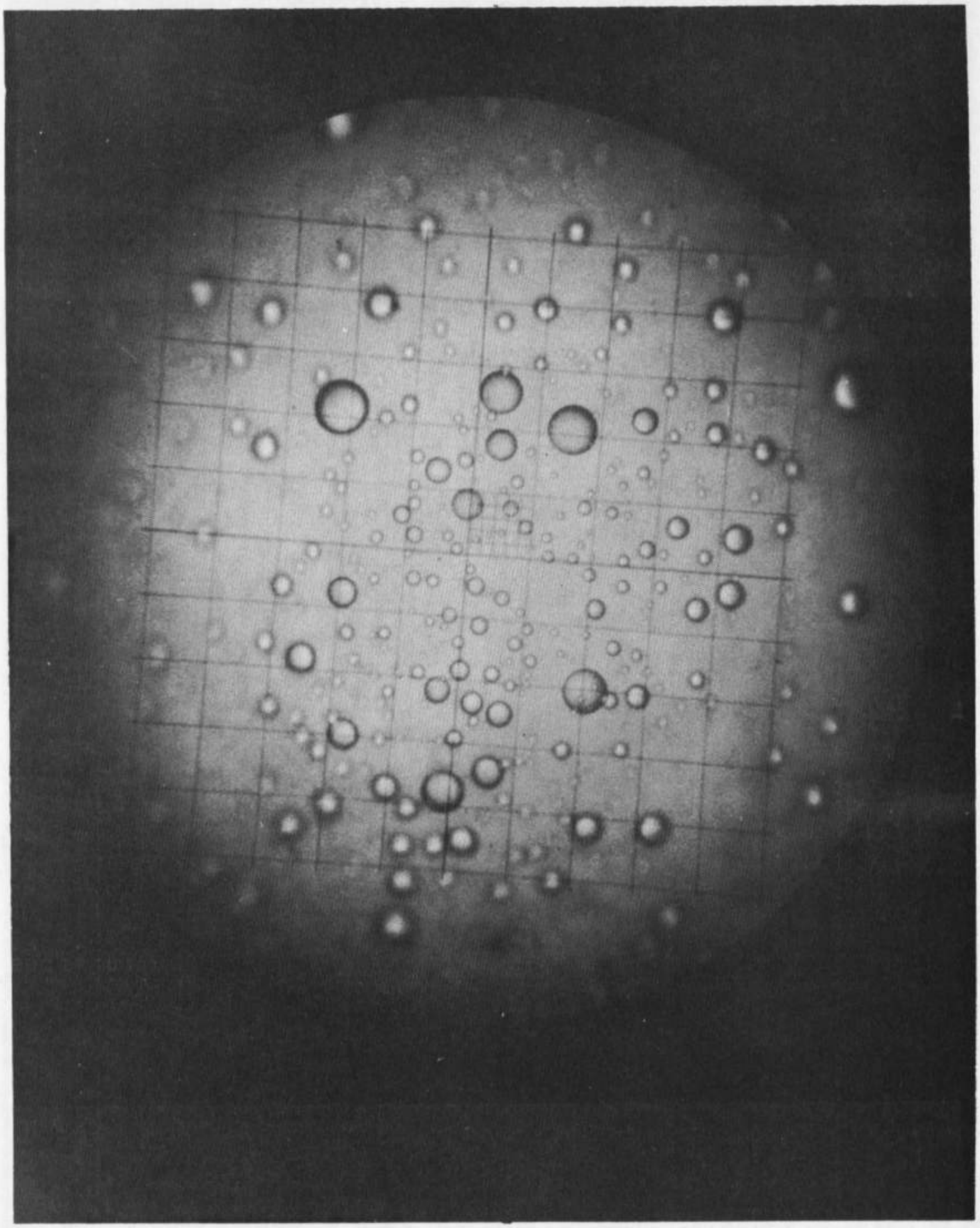


Fig. 11 Photograph of Droplets Collected with an Oil Slide

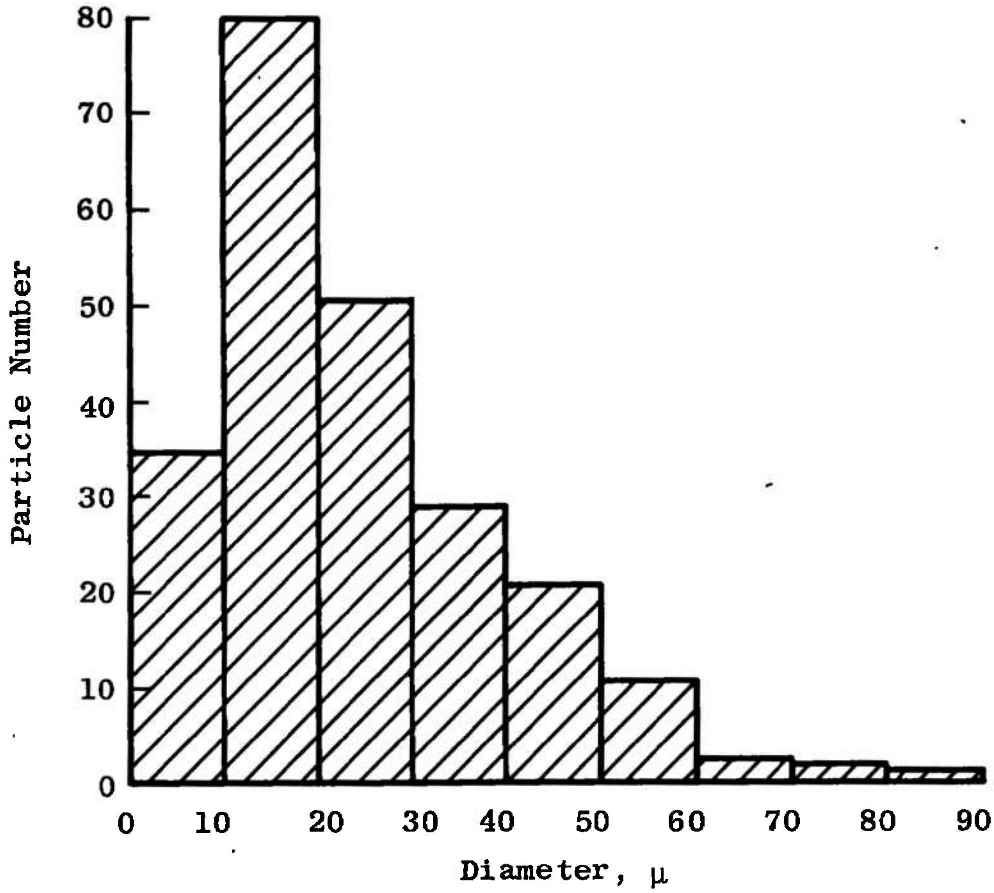


Fig. 12 Histogram of Particle Sizes Using Oil Slide Photograph

Probably the major source of error for the data desired from the hologram images will lie in the nonuniformity of the particle shapes. As may be seen from Fig. 9, most of the particles are not of a round shape but are distorted in various dimensions. This means that an observer reducing this data must make a judgement as to the dimension which he desires to record and continue to be consistent about the measurement throughout the analysis. The nonuniformity of particle shapes creates errors in the water content calculations which could be made from the hologram images. Therefore, it is most desirable that before reconstruction, a standard be set for the level of noise rejection and for the diameter or chord dimension which is to be measured for each particle image.

SECTION IV
CONCLUSIONS

A successful experimental effort established a holographic technique in a high-vibration environment. The hologram reproduces the droplet flow accurately and, therefore, produces a great deal of information which is needed but requires much time to reduce manually. It is felt, however, that electronic techniques are currently available which can handle the high density of data in these holograms to the extent that the holocamera can indeed be used as an operational instrument for the application which was discussed in this report.

The holocamera described in this report had several limitations that are attributable to the conjugate image overlap problem and the resolution of the lens used. By reducing the field of view and depth of field, higher magnification can be obtained and smaller particles can be observed. The smallest particles which were observed in these experiments were approximately 5 μ in diameter, although the data appear somewhat questionable.

The fundamental requirements for an electronic reconstructed image analyzer are that it have a wideband noise rejection capability and that it have a high information storage and sorting capability which can be done quickly and automatically.

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13. ABSTRACT

A series of experiments was performed in Engine Test Facility Propulsion Development Test Cell (J-1) at the Arnold Engineering Development Center to show that holography could be used to determine the water droplet information necessary to simulate the desired conditions in an operational environment. The experiments demonstrated the feasibility of applying holography to the visualization of small water droplet flow fields in a testing environment for droplet sizes down to approximately 15 μ.

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